Qualification and Reliability Testing of a Microchip Laser System for Space Applications

Malcolm Wright, Don Franzen, Hamid Hemmati, Mike Sandor
JPL, California Institute of Technology
July, 2003

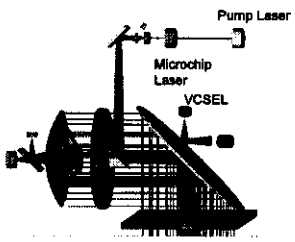
Malcolm.Wright@jpl.nasa.gov

Outline

- Introduction
  - Laser system
- Requirements
  - Performance
  - Environmental
  - Reliability issues
- Qualification testing plan
  - Screening
  - Qualification
- Results
  - Lifetest
  - DPA
  - PIND
  - Temperature Cycle
  - Vibration
  - Constant Acceleration
- Summary

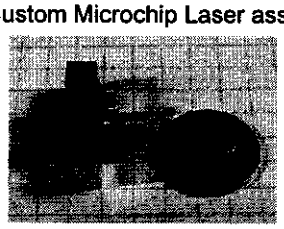
Introduction

- Pulsed laser required for compact space-borne scanning laser radar system
- Applications:
  - Autonomous rendezvous and docking
  - Smart lander
  - Imaging lidar
- Technology demonstration ⇒ make use of commercial components

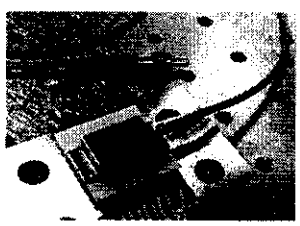


Laser System

Custom Microchip Laser assembly

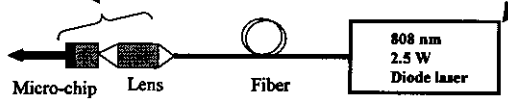


Commercial Semiconductor Laser



Pulsed, 1064 nm laser

10 μJ/pulse, 10 kHz, <1 ns, 17 mrad div, P_{avg} = 100 mW



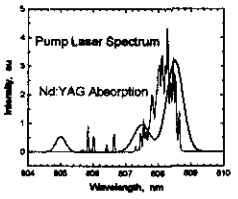
High power efficiency requires no TEC and hence remote placement of pump laser for thermal control

Pump Laser - requirements & specifications

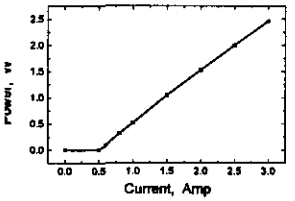
- Optical pump for solid state microchip laser
- Requirements:
  - High power
  - Fiber coupled
  - Fixed wavelength independent of temperature

- λ = 808 nm +/- 1 nm
- 2.5 W cw fiber coupled (200 um diam)
- Reliability an issue due to power and optical mode volume
- Qualification approach is procure and qualify commercial devices based on Telcordia.

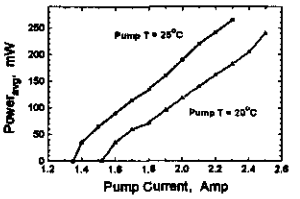
Spectra of pump laser



Pump Diode Laser Power



Microchip Power



System Environmental Requirements

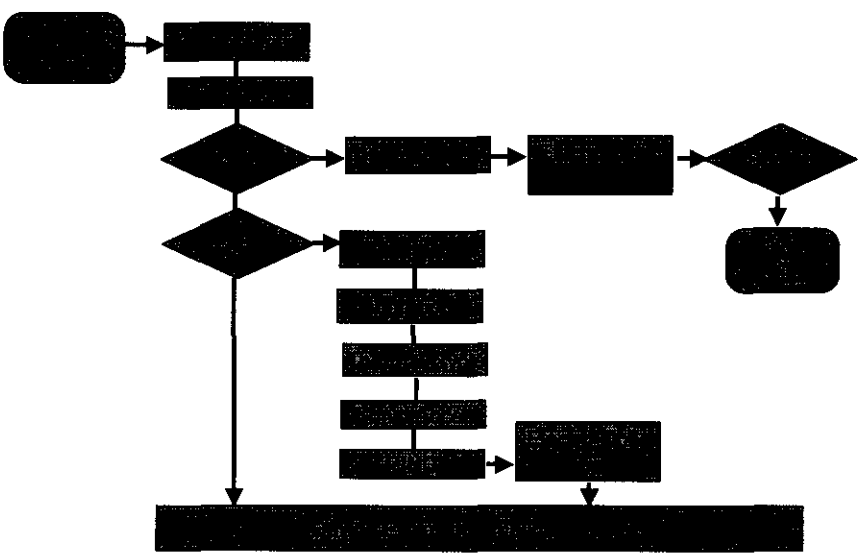
Lifetime	Operational	5000 hours MTBF
	Non-operational	5 years
Vibration	Random	1 min/axis 14.4 g(rms)
	20-50 Hz	0.01 - 0.15 g^2/Hz
	50-800 Hz	1 g^2/Hz
	800-2000 Hz	1 - .065 g^2/Hz
Pyro Shock	100-1500 Hz	100 – 1800 g
	1500-10000 Hz	1800 g
Thermal	Operating	-20 to 30 ° C
	Non-operating	-40 to 50 ° C
	Cycling	3 cycles 144/24 hrs hot/cold
	Storage	Max Temp
Pressure	Space	TBD
Shielding	EMC	Isol., cond., rad.
	ESD	TBD
Radiation		≤ 20 krad/year by design behind 100 mils Al
Laser safety	Ground operations	

Laser Performance/Reliability Issues

- Critical parameters
  - Output power, wavelength stability (especially pump laser), linewidth
  - Drive current, efficiency, temperature range
- Semiconductor laser failure mechanisms
  - Mechanical: Die shear, wire bond fail, fiber pull
  - Metal electrode and solder stability: soft – diffusion, hard – instability
  - Device dislocations and defects
  - Facet damage – oxidation and COD
  - Bandgap shrinking – facet heating
  - Optical mode quality
  - Radiation damage (eg 0.01 dB/krad penalty)
- Telcordia (Bellcore) standard used in fiber optic industry
  - Defines testing, performance and evaluation criteria
  - Generally meet or exceed environmental system requirements

Custom qualification testing flow based on Telcordia standard

Testing Flow



Qualification Test Plan: Screening Flow

Step	Screen	Required	Reject Criteria	SS	Special Instructions	Comments
1	DPA	Visual, bond pull,fiber pull, pure tin on leads verification	Mil-Std-883 where applicable	2	passed	Destructive test ; samples taken from Flight lot; Done at JPL
2	Serialization	Markem Ink only	N/A	All Flt Devices	passed	
3	Electricals	Test to data sheet @ +20C,+25C,	Data to be recorded	All Flt Devices	passed	Non-destructive correlation test units used to verify test setup and fixtures.
4	Temp Cycle	Ta = -40C/+60C (2degree C /min) and (10 degree C /min)	10 cycles	All Flt Devices	passed	Non-destructive test used to screen flight parts.
5	X-Ray	Active chip attach to heat sink	Voids of 10% or greater will be noted.	All Flt Devices	passed	Non-destructive test used to screen flight parts.
7	Electricals	Test to data sheet @ +20C,+25C	Data to be recorded	All Flt Devices	passed	Non-destructive test used to screen flight parts.
8	Burn-in	(+40C Tj) 80% Rated Power 24 hours	N/A	All Flt Devices	passed	Non-destructive test used to screen flight parts. Done by vendor
9	Electricals	Test to data sheet @ +20C,+25C	Data to be recorded	All Flt Devices	passed	Non-destructive test used to screen flight parts.

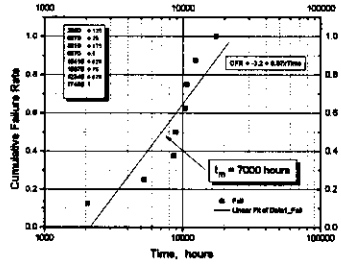
Qualification Test Plan: Qualification Flow

Life Test (Burn-In)	(+60C Tj) 80% Rated Power 500 hours	N/A	4 from step 9	passed	Destructive test used to qualify flight parts.
End Point Electricals	Test to data sheet @ +20C,+25C	Data to be recorded		passed	Destructive test used to qualify flight parts.
Temp Cycle Qual	Ta = -40C/+60C (2 degree C /min) and (5 degree C /min)	50 cycles	2	passed	Destructive test used to qualify flight parts.
End Point Electricals	Test to data sheet @ +20C,+25C	Data to be recorded		passed	Destructive test used to qualify flight parts.
ESD	HBM TBD		2	passed	Destructive test used to qualify flight parts.
End Point Electricals	Pre & post test to data sheet @ +20C,+25C with pre and post ESD input diode forward/reverse curve recorded using curve tracer	Data to be recorded		passed	Destructive test used to qualify flight parts.
Vibration	MIL 883 Method 2007 Cond A		2	passed	Destructive test used to qualify flight parts.
End Point Electricals	Test to data sheet @ +20C,+25C	Data to be recorded		passed	Destructive test used to qualify flight parts.
Internal Moisture	MIL-STD-883 Method 1018	Max 5000 ppm water vapor	2	passed	Destructive test used to qualify flight parts.
PIND	MIL-STD-883 Method 2020		2	1 passed 1 anomoly	Nondestructive test used to qualify flight parts.
Constant Acceleration	Mil 883 Method 2001 Cond B		2	2 failed	Destructive test used to qualify flight parts.

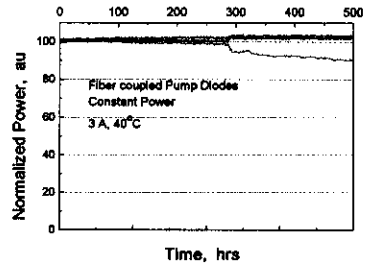
Life Test – analysis and results

- Laser life test requirements based on Arrhenius model with assigned activation energy
- 5000 hours at 25° C ⇒ requires 500 hour test at 40° C base temperature (junction temp ~ 60° C)

C-mount Diode Laser, 3 W, 40°C Failures



Packaged Diode Laser Lifetimes



DPA Results

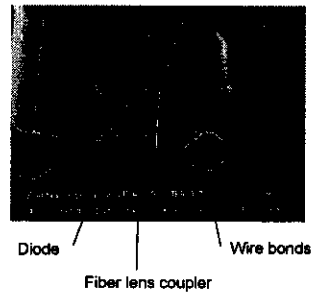
Destructive Parts Analysis performed on initial sample

Results:

External Visual	Mil Std 883 Meth 2009	Pass
Hermiticity	Mil Std 883 Meth 1014.1 C	N/A fail He fine leak.*
RGA	Mil Std 883 Meth 5009	N/A
Internal Visual	Mil Std 883 Meth 2017 A	Pass
Bond Pull	Mil Std 883 Meth 2011	Multiple, avg. pass
SEM Analysis	Mil Std 883 Meth 2018	Pass
Die Shear	Mil Std 883 Meth 2019	Pass

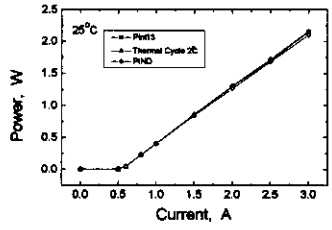
* The part was subjected to fine leak only to verify the lack of hermeticity. The high leak rate is most likely due to the absorption of helium by the sealant around fiber coupling during the 2-hour pressurization at 45 psig.

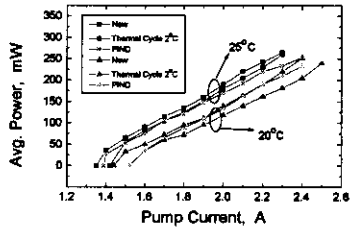
SEM Photo – 35x



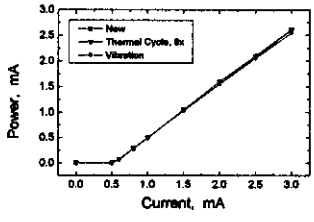
PIND & Vibration Results

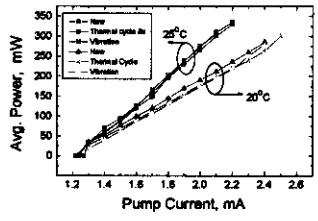
- PIND: Shock + acoustic (1000 g's followed by 10 g's @ 60 Hz)





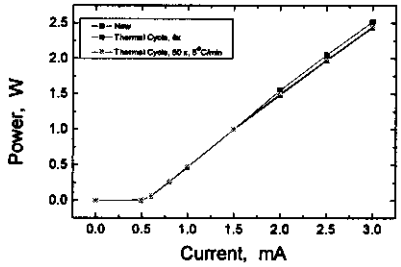
- Vibration: 20 g's, 20 – 2kHz, random 3 axis

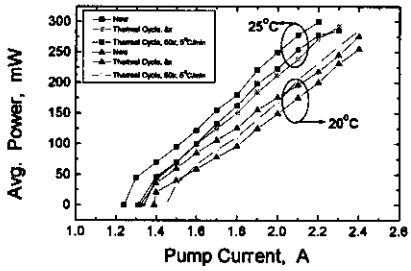




Temperature Cycling

- Temperature cycled: –40° C to 60° C, 2° C/min - 8x screening,
  5° C/min - 50 x qualification

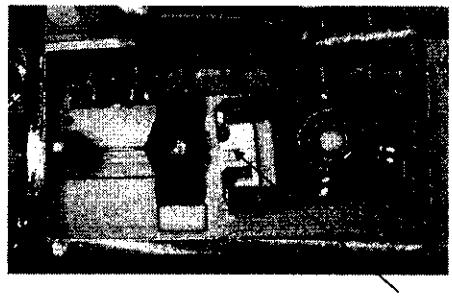




No significant difference between cycling at 2° C/min and 5° C/min for 50 cycles each

Constant Acceleration and final DPA

- Test: 5000 g's 3 axis, 2 orientations /axis, 1 min each axis



Device failure: note fiber – diode misalignment

Summary

- Qualification test plan developed for high power laser diodes. Telcordia (Bellcore) qualification has similar requirements.
- Commercial pump laser diodes can be qualified for space applications.
- Packaging does not meet high acceleration environment.